SUSTAINABLE
ENERGY AUTHORITY
OF IRELAND

Heating Behaviour in Ireland

Analysis of 2023 data from the Behavioural Energy and Travel Tracker

SEAI Behavioural Economics Unit

Behavioural insights for policy: primary research

Rialtas na hÉireann
Government of Ireland

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Sustainable Energy Authority of Ireland

SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

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Executive Summary

Background

Space heating is the single most energy intensive activity that takes place in Irish homes, accounting for over half of annual energy use in the residential sector and is a significant contributor to Ireland's greenhouse gas emissions.

Understanding how people heat their homes is important for two main reasons:

- Assumptions about heating behaviour are central to energy performance models, such as the Dwelling Energy Assessment Procedure (DEAP) that underpins the calculation of a dwelling's Building Energy Rating (BER). Previous research suggests that current assumptions in simplified models like DEAP may overestimate heating demand.
- Measures of heating behaviours and the factors that underpin them are needed to design and target interventions to reduce heat demand through behaviour change without negatively impacting on wellbeing.

In this report, we make use of the rich dataset generated by Ireland's Behavioural Energy and Travel Tracker (BETT) to examine heating behaviour in more detail. Findings are based on data collected monthly throughout 2023, using a nationally representative sample of 1,000 people for each wave. The use of behavioural science techniques ensures greater accuracy and detail compared with traditional survey methods.

Main findings

Although there is a high degree of variability in heating behaviour, our data support existing evidence that currently used energy performance models significantly overestimate average heat demand:

- During the heating season (October to May) people heat their homes for an average of just under 4 h a day – half the duration assumed in the DEAP. Just 15% heated their homes for 8 h or more.
- People typically use thermostat settings of 20°C for living spaces, rather than 21°C as assumed in the DEAP.

We also report a number of findings regarding factors that are related to heating behaviour and energy expenditure:

- Heating behaviour is not uniform across the entire October to May heating season. There are shoulder seasons in which only some households use heating, or households using heating do so only on some days.
- All aspects of weather (rainfall, sunshine, windspeed) affect heating behaviour, not just outdoor temperature. The sharpest decline/increase in heating is seen around outdoor temperatures of 12°C.
- Heating behaviour varies greatly across different dwelling archetypes, particularly in terms of reliance on secondary heating. For example, oil-heated homes are more reliant on secondary heating than gas-heated or heat pump homes.
- Dwelling and heating system type have a much greater influence on energy bills than a dwelling's BER, but the presence of a thermostat to control room temperature has no relationship with energy bills.
- Worry about cost of living and worry about climate change are associated with different aspects of heating behaviour. Those worried about the cost of living were less likely to use heating in the first place but those worried about climate change tended to heat for less time and use lower thermostat settings.

Conclusion

This report adds to existing evidence that commonly used energy performance models significantly overestimate heating demand. Ideally, further research should be conducted validating BETT's self-reported methods against radiator temperatures or direct measures of home heating, and further evidence is still being collected on thermostat settings used outside of living areas. However, we consider the existing evidence base on heating duration to be strong enough to warrant changes to model assumptions in the DEAP. The report also highlights several factors that affect heating behaviour, which may in some cases warrant separate model assumptions, or at least caution in interpreting model predictions. These findings should also guide policy interventions to reduce heating demand through behaviour change.

We make some recommendations based on the report's findings in the boxes below:

Recommendations for energy performance models

- Change current DEAP assumptions to bring them closer in line with actual heating behaviour, particularly in terms of shorter heating periods.
- Consider adding nuance to DEAP calculations and/or related models to reflect shoulder seasons, differential use of secondary heating amongst different dwelling archetypes and different heating patterns required by new technologies such as heat pumps.

Recommendations for policy and communications

- Consider incorporating floorspace into a dwelling's BER to make it reflect total energy usage and better empower citizens to make choices that reduce their energy costs.
- Target interventions to curb excessive heating at those on higher incomes, while remaining mindful of increased heat requirements for older people and those with disabilities.
- Promote the adoption and use of adjustable thermostats specifically among those at risk of energy poverty so that this cohort can manage their heating bills easily by controlling temperature rather than avoiding using any heating at all.
- Investigate further the reason why social housing tenants are more likely to use high thermostat settings, and address this if appropriate.

1. Introduction

1.1. Background

Space heating is the single most energy intensive activity that takes place in Irish homes, accounting for over half of annual energy use in the residential sector, and a significant proportion of people's home energy bills.[1] Due to continued high dependence on fossil fuels, residential space heating is also a significant contributor to Ireland's greenhouse gas emissions – domestic space and hot water heating were responsible for about 10% of emissions in 2023, amounting to 5.35 Mt CO2.[2] Eliminating residential emissions from space heating through home energy upgrades is therefore an important component of Ireland's Climate Action Plan, and essential to Ireland reaching net-zero.[3]

Understanding how people heat their homes is important for multiple reasons. Assumptions around the number and duration of heating periods, as well as temperature set points, are central to the Dwelling Energy Assessment Procedure (DEAP) that underpins the calculation of a dwelling's Building Energy Rating (BER) as well as other models. Incorrect assumptions about heating behaviour could have knock-on effects on estimates of carbon emissions produced by a dwelling as well as estimated carbon and financial savings achievable from home energy upgrades.

Accurate measures of current heating behaviours and the factors that underpin them are also important for understanding how to design and target interventions to reduce heat demand through behaviour change. Initial analyses from Ireland's Behavioural Energy and Travel Tracker revealed the presence of inefficient heating behaviours such as using high thermostat settings, heating during the summer and heating unoccupied rooms.[4] On the other hand, the recent energy and cost-of-living crisis mean there is likely to have been an increase in people underheating their homes. A balanced approach to behaviour change is therefore required, targeting only those using heating in excess of their needs.

1.2. Previous research on heating behaviour

1.2.1. Measures of home heating behaviour

This report deals primarily with two different aspects of heating behaviour – heating schedules (including the use of primary/secondary heating and heating duration) and thermostat settings. Below we summarise existing evidence regarding measures of these, paying particular attention to evidence from Ireland and similar contexts.

Heating schedules

The DEAP assumes that a typical household heats their home for 8 h a day – from 7 am to 9 am and from 5 pm to 11 pm – throughout a "heating season" that spans October to May.[5] For homes where there is a secondary heating source present, it is generally assumed to provide 10% of the heating requirement. In the UK, the analogous Standard Assessment Procedure (SAP) assumes even longer heating times, with the evening heating period starting instead at 4 pm.[6] Measurements of heating schedules in the literature vary greatly, as do the methods used to estimate these, but generally point towards the model assumptions above being overestimates of actual observed behaviour.[7]

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[1] SEAI (2018). *Energy in the Residential Sector.* https://www.seai.ie/publications/Energy-in-the-Residential-Sector-2018-Final.pdf

[2] https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/residential/

[3] https://www.gov.ie/en/publication/67104-climate-action-plan/

[4] SEAI (2023) Behavioural Energy and Travel Tracker: Results report 1 – heating season 2022/2023. https://www.seai.ie/data-and-insights/behavioural-insights/publications/behavioural-energy-and-tr/

[5] SEAI (2024). Domestic Energy Assessment Procedure (DEAP) Version 4.2.6: Ireland's official method for calculating and rating the energy performance of dwellings. https://www.seai.ie/publications/DEAP_Manual.pdf

[6] BRE (2023). *The Government's Standard Assessment Procedure for Energy Rating of Dwellings: Version 10.2.* https://bregroup.com/documents/d/bre-group/sap-10-2-11-04-2023-pdf

[7] Azimisechoghaei, M. et al. (2022). Indirect based approaches to assessing the heating behaviours of occupants in residential buildings. *Civil Engineering Research in Ireland (CERI) 2022.*

There is little robust evidence regarding heating periods in Irish homes. One study of 67 homes that used electricity supply and room temperature data from 2011-2013 to estimate heating schedules found that these homes used heating for approximately 5 h a day; only about 55% had two heating periods a day.[8] However, these were primarily detached houses within a small geographical area that had undergone retrofitting, and are unlikely to be representative of the wider population. An earlier study of 358 oil and gas-heated homes in the UK as part of the Carbon Reduction in Buildings (CaRB) project estimated longer average heating times of over 8 h, based on internal room temperatures.[9] However, a later comparison of different measurement types found that room temperature-based methods tend to overestimate heating duration by 3 to 5 h. It estimated daily heating times of 2.9 h to 3.3 h when based on radiator temperatures instead.[10]

All indirect methods of measuring heating use and duration have drawbacks – obtaining measures that are both objective and representative is difficult. The present study is not without its own limitations but through our use of a nationally representative dataset we address some of the drawbacks of previous estimates.

Room thermostat temperatures

The DEAP assumes a setpoint of 21°C in living spaces and 18°C in other spaces during heating periods. Like measures of heating duration, estimates of thermostat temperatures used in homes vary between studies. Previous evidence from Ireland suggests that 21°C is an overestimate of the temperature to which people heat their living spaces but that 18°C is an underestimate of the temperature to which they heat other spaces.[8,11] This is consistent with our previous finding from BETT that approximately one third of people heat empty rooms on a given day in winter, to the same temperature they heat their living spaces. It is worth noting, however, that less than half of people in Ireland report that their home has a thermostat installed to control the room temperature, so for many this temperature is not a conscious choice.

1.2.2. Factors influencing heating behaviour

In this report we investigate the relationship between different aspects of heating behaviour and

- weather and temporal factors,
- dwelling characteristics,
- sociodemographic characteristics, and
- psychological factors.

This is not an exhaustive list of potential influences on heating behaviour, an analysis of price elasticity is beyond the scope of this report for instance, but rather reflects our research priorities and the data readily available through BETT.

Weather and time

It is self-evident that outdoor temperature should affect use of space heating. Due to the non-linear relationship between temperature and heat demand, "heating degree-days" tend to be used when exploring this link rather than temperature itself. These are determined by calculating the degrees below a given "base temperature" above which it is assumed there is no need for space heating on a given day (see Appendix A2 for full description). Other aspects of weather may also affect heating behaviour. A study using data from Ireland's Smart Metering Gas Consumer Behavioural Trial found that all weather variables, including sunshine, rainfall and windspeed, were related to gas consumption.[12]

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[8] Hunter, W, Hoyne, S & Noonan, L. (2017). Evaluation of the Space Heating Calculations within the Irish Dwelling Energy Assessment Procedure Using Sensor Measurements from Residential Homes. *Energy* Procedia 111, 181-194. https://doi.org/10.1016/j.egypro.2017.03.020

[9] Shipworth, M. et al (2009). Central heating thermostat settings and timing: building demographics. *Building Research & Information*, 38(1), 50–69. https://doi.org/10.1080/09613210903263007.

[10] Kane, T. et al. (2017). Heating behaviour in English homes: An assessment of indirect calculation methods. *Energy and Buildings 148*, 89-105. http://dx.doi.org/10.1016/j.enbuild.2017.04.059

[11] Moran, P & Goggins, J (2020) Can DEAP help us to predict the energy demand and indoor temperature of homes before and after renovation? A case study from Dublin. *Civil Engineering Research in Ireland (CERI) 2020.* https://researchrepository.universityofgalway.ie/entities/publication/3ea6df57-c15c-4581-b516-9c8171582b96

[12] Harold, J, Lyons, S & Cullinan, J (2015). The determinants of residential gas demand in Ireland. *Energy Economics 51*, 475-483. https://doi.org/10.1016/j.eneco.2015.08.015.

Besides weather conditions, there is also evidence that heating demand varies systematically at different times, with gas consumption and heating durations typically found to be longer on weekends and public holidays compared with weekdays, although differences are small.[9,12]

Dwelling characteristics

Links between dwelling characteristics (age, size, type, BER) and heat demand are well established. Older, larger, detached homes typically require the most energy to heat and newer, smaller, apartments the least.[12,13] It is less clear, however, to what extent the actual heating behaviour of the occupants varies according to different dwelling characteristics.

For the most part, the DEAP assumes uniform occupant behaviour in terms of heating schedules, temperature setpoints and use of secondary heating, regardless of dwelling characteristics. However, evidence from the literature suggests this might not always be the case. The UK CaRB study mentioned above found detached homes are heated for longer on average than mid-terrace homes.[9] In an Irish context, the weak relationship between energy consumption and BERs suggest that occupant behaviour may differ between homes with different energy efficiencies.[14,15]

Another dwelling characteristic that might influence occupant heating behaviour is the presence or absence of heating controls. There is a general assumption that adjustable room thermostats save energy and reduce heating bills, with smart thermostats claimed to provide even greater savings. However, there is some evidence that smart technologies may fail to deliver promised energy savings due to user behaviour that differs from that assumed by energy performance models.[16]

Sociodemographic factors

There have been links found between heat demand (as measured by gas consumption) and some sociodemographic characteristics of dwelling occupants, including in an Irish context.[12,13] Older people are generally found to have higher gas consumption, possibly due to spending more time at home. Those on higher incomes also tend to use more heating in international studies, and space heating demand has reduced in Ireland in recessionary times.[17] Household size, higher education and being a homeowner have also been linked to higher gas consumption. There is no evidence of a gender effect, despite some evidence that women have a preference for warmer temperatures than men.[18]

Psychological and other factors

Research looking specifically at the link between psychological factors and heating behaviour is sparse. One Dutch study found a link between environmental values, identity and social norms and reduced gas consumption.[13] Further, results from the Irish Smart Metering Gas Consumer Behavioural Trial found a reduction in gas use amongst households in a treatment group that received various demand side interventions, including providing the household with additional information on their gas usage, a more frequent bill, the provision of an In House Display (IHD) unit and the introduction of a variable tariff.[12]

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[13] Namazkhan, M, Albers, C & Steg, L (2020). A decision tree method for explaining household gas consumption: The role of building characteristics, socio-demographic variables, psychological factors, and household behaviour. *Renewable and Sustainable Energy Reviews 119,* 109542. https://doi.org/10.1016/j.rser.2019.109542.

[14] Coyne, B & Denny, E (2021). Mind the Energy Performance Gap: testing the accuracy of building Energy Performance Certificates in Ireland. *Energy Efficiency 14*, 57. https://doi.org/10.1007/s12053-021-09960-1.

[15] https://www.cso.ie/en/releasesandpublications/ep/p-dberngs/householdgasconsumptionbybuildingenergyratings2023/

[16] Brandon, A, et al. (2022). The human perils of scaling smart technologies: evidence from field experiments. *National Bureau of Economic Research Working Paper Series 30482*. https://doi.org/10.3386/w30482.

[17] Dennehy, ER, et al. (2019). Recession or retrofit: An ex-post evaluation of Irish residential space heating trends. *Energy and Buildings 205*, 109474. https://doi.org/10.1016/j.enbuild.2019.109474.

[18] Karjalainen, S. (2007). Gender differences in thermal comfort and use of thermostats in everyday thermal environments. *Building and environment 42* (4), 1594-1603. https://doi.org/10.1016/j.buildenv.2006.01.009.

There is also evidence that social norms and climate change concern are related to pro-environmental behaviours more generally.[19,20] In our broader analysis of BETT data we found that self-reported understanding of how to save energy and worry about climate change were the psychological factors most strongly associated with energy behaviour, although their influence was generally less than that of sociodemographic factors.[4]

1.3. Scope of this report

In this report we make use of the rich dataset generated by BETT (see box below) to examine heating behaviour in more detail, focusing specifically on monthly data collected in 2023.[4] We report up-to-date measures of different aspects of space heating behaviour – heating use (both primary and secondary), heating duration and thermostat settings for room temperature. We also use a regression modelling approach to investigate the factors that influence these behaviours.

Ireland's Behavioural Energy and Travel Tracker

The Behavioural Energy and Travel Tracker (BETT) is a nationally representative online survey designed by SEAI's Behavioural Economics Unit. The tracker uses a behavioural science technique known as the "Day Reconstruction Method" to gather accurate and granular data about travel and home energy behaviours in Ireland. It also collects data on factors that may be related to energy behaviours, such as psychological factors, energy poverty, and dwelling and sociodemographic characteristics. BETT ran monthly from December 2022 to December 2023 and continues to run on a quarterly basis.

While the data are self-reported and therefore subject to a certain level of error, the use of behavioural science methods to improve recall and reduce social desirability bias ensures a greater level of accuracy compared with traditional survey methods. The dataset also has the distinct advantage of having been generated from a large (1,000 participants for each wave), nationally representative sample.

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[19] Allcott, H. (2011). Social norms and energy conservation. *Journal of public Economics*, 95(9-10), 1082-1095. https://doi.org/10.1016/j.jpubeco.2011.03.003

[20] Bouman, T., et al. (2020). When worry about climate change leads to climate action: How values, worry and personal responsibility relate to various climate actions. *Global Environmental Change*, 62, 102061 https://doi.org/10.1016/j.gloenvcha.2020.102061

2. Methodology

2.1. Sampling and data collection

We use data from Ireland's Behavioural Energy and Travel Tracker (BETT) survey. The data used for this analysis were collected monthly from January to December 2023 (12 waves, each run over seven or eight days towards the start of each month). Each wave was run online with a sample of 1,000 participants, recruited by a market research company, that was approximately representative of the Irish population in terms of gender, age, geographical region, and social grade, resulting in a total sample size of n=12,000. Participants could partake in multiple, but not consecutive waves. Respondents were paid €4 and typically took about 15-20 minutes to complete the survey.

2.2. Survey design

A full description of BETT is available elsewhere.[4] Here we briefly describe sections directly relevant to the analysis presented in this report.

2.2.1. Day reconstruction & energy behaviour

BETT adapts the Day Reconstruction Method[21] to measure energy behaviours performed on one given day (the day preceding data collection). Participants are first prompted to think through the previous day and make a note of any energy-related behaviours. We do not analyse these notes – they serve only to improve participant recall for subsequent parts of the survey. Following this, participants respond to detailed questions about travel behaviour, heating, hot water use, cooking and electrical appliance use, with branching used to ensure participants only answer questions of relevance to them.

Heating behaviour

Participants are first asked whether their home was heated on the reference day using (a) central heating (including storage heaters) (b) portable heaters (c) an open fire/stove/range or (d) electric underfloor heating. For each of these that they used they are then asked detailed follow up questions including about duration (in 1 h timeslots up to 12 h, or 12 h or more) and time of day used. Exact wording of questions related to heating behaviour can be found in Appendix A1.

2.2.2. Additional variables

Once participants have completed the day reconstruction task, we collect data on a range of other factors that might be related to their behaviour: psychological factors, energy expenditure, and dwelling and sociodemographic characteristics. Within the section on dwelling characteristics we ask whether their home has a thermostat installed. If they answer positively, we follow this with a question about the current temperature set point for living spaces.

2.3. Data analysis

2.3.1. Measures of heating behaviour

Measures of heating behaviour presented in Section 3 are derived directly from participants' responses. For heating duration, we take the midpoint of the timeslot chosen (e.g. "1 – 2 hours" would be assigned a duration of 1.5 h), unless the participant has selected "12 hours+", in which case we assign a duration of 16 h. For total duration, we take the sum of all durations reported for each type of heating.

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[21] Kahneman, D. et al (2004). A survey method for characterizing daily life experience: The day reconstruction method. *Science*, 306(5702), 1776-1780. doi: 10.1126/science.1103572

2.3.2. Modelling approach

To investigate what factors are related to heating behaviour we run logistic regression models with the following six binary dependent variables:

- Using primary heating (central or underfloor)[22].
- Using secondary heating (open fire/stove or portable heaters).
- Using primary heating for (a) over 2 h and (b) over 4 h (given primary heating was used).
- Using thermostat settings of (a) 19°C or over and (b) 21°C or over (given primary heating was used and a thermostat is installed in the home).

We include a range of independent variables in our model to investigate their relationship to the behaviours above:

- **Weather/temporal factors**: time of year (heating season vs. summer), day of the week (weekday vs. weekend), heating degrees (using a base temperature of 15.5°C),[23] rainfall, sunshine, windspeed.
- **Dwelling characteristics:** dwelling type, BER, central heating system, thermostat type.
- **Sociodemographic and household characteristics:** gender, age, household disposable income, education, employment status, location (urban vs. rural), tenure, household size, and presence of (a) under 18s (b) over 65s or (c) disability in the household.
- **Psychological factors:** worry about (a) cost of living and (b) climate change, self-reported understanding of how to save energy.

The psychological factors mentioned above are transformed from 7-point scales into binary variables by denoting responses at or above the median as "high" and below the median as "low".

In addition to models of behaviour, we also investigate the relationship between dwelling characteristics and total household energy bills (heating, electricity, and other fuels) over the preceding month through a linear regression model,[24] while controlling for survey wave (to account for seasonality and price changes) and sociodemographic characteristics.

Regression tables are included in Appendix A5 and referred to throughout Section 4.

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[22] Underfloor heating is grouped with central heating due to heat pump owners apparently classifying this as underfloor electric heating.

[23] See Appendix A2 for a description of how this is calculated.

[24] Taking the cube root of the dependent variable to correct for heteroskedasticity.

3. Results - measures of heating behaviour

3.1. Use and duration of space heating

Patterns of space heating duration across the year can be seen in Figure 1. As expected, average daily hours of heating were higher during heating season of October to May. There was, however, considerable variation within this, with shorter heating durations seen in the shoulder months of April, May, October, November compared with the coldest months of December to March. Similar patterns are seen for all types of space heating, as well as when tracking the percentage of people using heating or number of days per week heating is used, as opposed to average heating duration (see Figure 7 in Appendix A4).

Figure 1: Mean number of hours for which each type of heating was used in a given day and mean outdoor temperature for each survey wave in 2023. Where a participant was not home on the reference day or did not use a given heating type a duration of 0 h is assigned. Portable heaters and underfloor heating are pooled due to low prevalence. Total heat duration is taken to be the sum of duration for each heating type. Shading indicates waves conducted during the heating season.

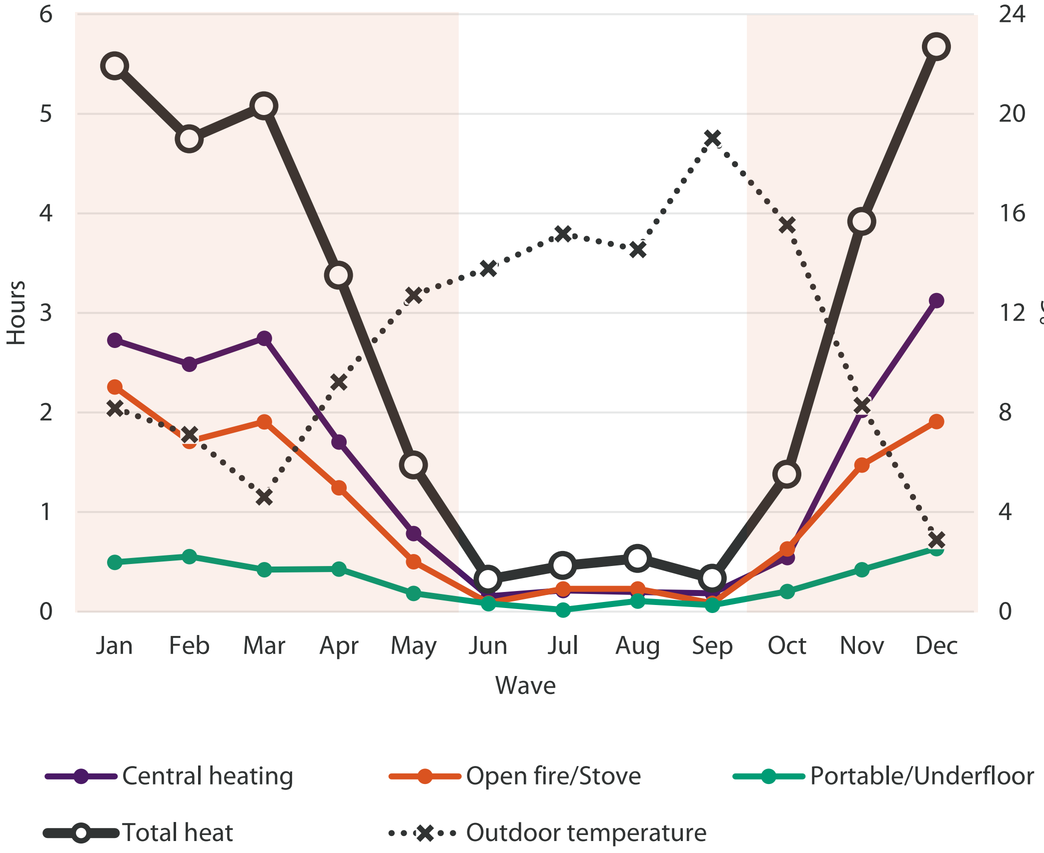


Table 1: Summary statistics regarding the proportion of participants using each type of space heating in a given day and the duration of time for which they are used (mean and standard deviation), in (a) months outside the heating season (June to September) (b) the heating season (October to May) and (c) the four coldest months (December to March).

	Proportion using			Duration if used (h)			Overall duration (h)		
Type of heating	Jun-Sep	Oct-May	Dec-Mar	Jun-Sep	Oct-May	Dec-Mar	Jun-Sep	Oct-May	Dec-Mar
Central heating	9%	59%	72%	2.1 (±2.8)	3.4 (±2.9)	3.9 (±3)	0.2 (±1)	2 (±2.8)	2.8 (±3.1)
Fire or stove	4%	26%	33%	4.1 (±3.6)	5.7 (±3.3)	6 (±3.3)	0.2 (±1)	1.5 (±3)	1.9 (±3.4)
Portable	1%	7%	10%	1.7 (±1.2)	3.1 (±3)	3.1 (±3)	0 (±0.2)	0.2 (±1.2)	0.3 (±1.3)
Underfloor	1%	2%	3%	6.5 (±7.1)	7.7 (±6.4)	7.9 (±6.1)	0 (±0.8)	0.2 (±1.6)	0.2 (±1.7)
Any heating	**14%**	**75%**	**89%**	**2.9 (±3.6)**	**5.2 (±4.2)**	**5.9 (±4.3)**	**0.4 (±1.7)**	**3.9 (±4.3)**	**5.2 (±4.5)**

Heating use and duration for different periods of the year are summarised in Table 1. We find that three quarters of people use some form of heating in a given day during the heating season (four in five of those who were home on a given day), rising to 9 in 10 during the coldest months of December to March (95% of those who were home). Of those that used heating, about four in five used central heating and over a third used an open fire or stove, with smaller proportions using other forms of secondary heating. Although space heating is much less prevalent in the summer months, it is not non-existent – about one in seven people used some form of space heating on a given day between June and September.

During the heating season (October to May), those who heated their homes did so for a total of up to 5.2 h on average, rising to 5.9 h during the coldest months (December to March). When looking at the population as a whole (including those who did not use heating on the reference day) this translates to an average of 3.9 h of daily heating, or 5.2 h for the coldest months. There was a high degree of variability around these mean estimates, but just 15% of the sample heated their homes for 8 h or more during the heating season, as assumed in the DEAP.

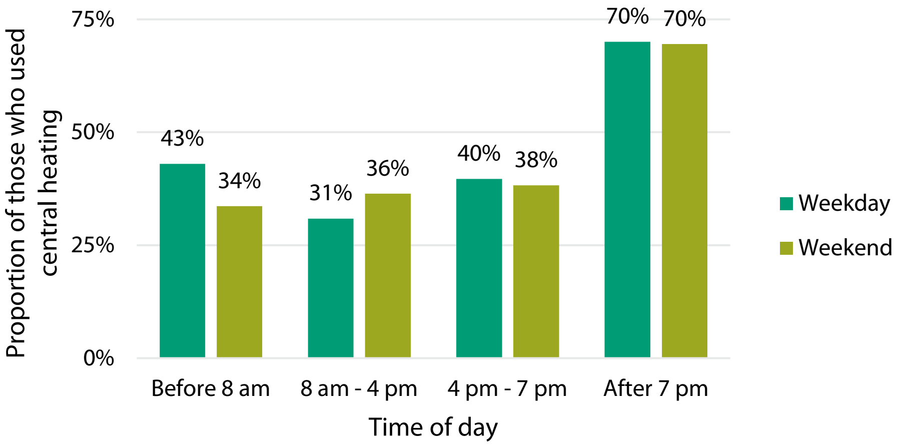
Central heating, if used, was on for 3.4 h a day on average over the heating season. Portable heaters were used for times comparable to this (3.1 h a day), while open fires/stoves and underfloor heating were used for longer durations (5.7 h and 7.7 h respectively). We believe the long durations reported for underfloor heating are partially due to heat pump owners reporting their space heating as electric underfloor heating rather than central heating (despite instructions to do otherwise). For this reason, we group underfloor and central heating together as “primary heating” for further analyses.

It is worth noting that the estimates reported above include all participants, including participants who were not home at all on the reference day (about 5% of the sample during the heating season) and those who may be underheating their homes due to energy poverty. Just under a quarter of participants reported having had to go without heat in the preceding month through lack of money during the heating season months. If these are excluded, our average total heating time increases by about 0.2 h.

3.1.1. Timing of central heating use

As well as duration of use, participants who used central heating are also asked what time(s) of day it was used, the results of which are shown in Figure 2. Most people who used central heating (70%) used it in the evening after 7 pm., with less than half using it during each of the other time periods asked about.[25] Timing of central heating use followed similar patterns on weekends/public holidays compared with weekdays, other than fewer using it in the morning before 8 am and more using it during the day from 8 am to 4 pm.

Figure 2: Times of day during which central heating was used, for those participants who used central heating on the reference day (n=5,081), split by weekdays and weekends.

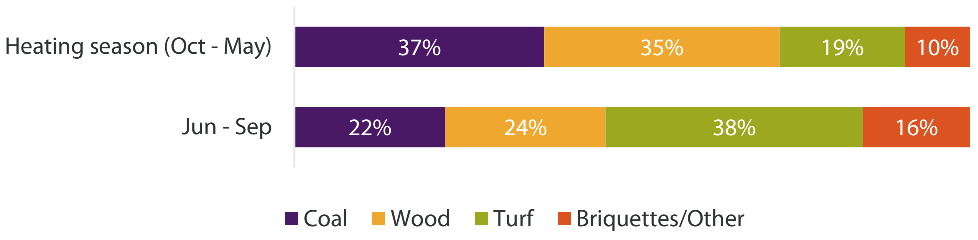


3.1.2. Secondary heating fuels

As outlined above, use of secondary heating was quite prevalent in our sample – just under a third of participants lit an open fire/stove or used portable heaters in a given day during the heating season, rising to two in five in the coldest months. For those participants who used secondary heating, we ask follow-up questions regarding fuels used.

Of those who used portable heaters, 84% reported using electric heaters with 20% using other types. Fuel types used in open fires and stoves are shown in Figure 3. During the heating season, most people used coal or wood, whereas turf was the most prevalent fuel used in the summer (although it should be noted absolute use of all fuels is much lower).

Figure 3: Share of fuels participants reported using for open fires and stoves, split between the heating season (n=2,047) and other months (n=152).



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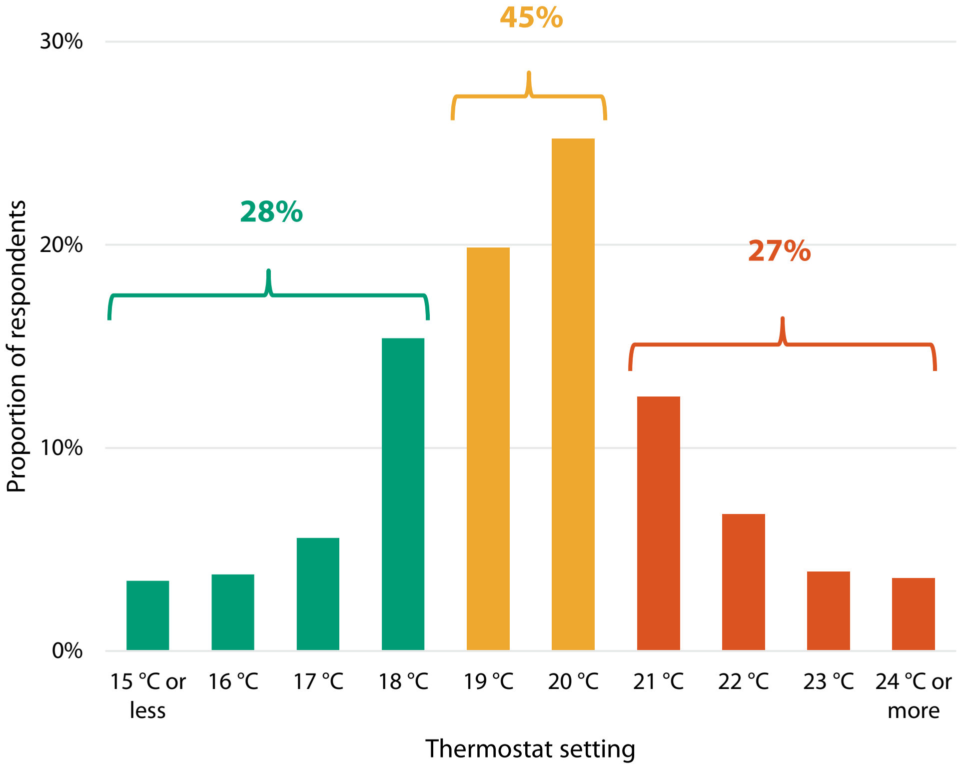
[25] These time periods were chosen to reflect different time bands for electricity time-of-use tariffs to enable analysis regarding timing of electricity consumption, as opposed to investigating timing of heat demand. As such, the data do not allow detailed analyses regarding the number and timing of heating periods.

3.2. Room temperature settings

Figure 4 shows thermostat settings used in living spaces by participants who used central heating on the reference day. Note that these results pertain only to those participants who report owning a thermostat – half of participants do not own a thermostat and a further 6% did not know if they did. The mean thermostat setting used by participants was 19.5 °C and the mode/median was 20°C, although there was considerable variability around this. Over a quarter of participants reported using relatively high thermostat settings of 21°C or more.

Figure 4: Thermostat settings for living spaces used by participants that own a thermostat and used central heating on the reference day, excluding those who didn't know what setting was used (n=2,462).



4. Results - factors influencing heating behaviour

Full regression tables showing the relationship between different factors and (a) use of primary heating (b) use of secondary heating (c) duration of primary heating if used and (d) thermostat temperature settings can be found in Appendix A5. In this section we summarise the main findings regarding each type of factor in turn, but note that all factors were included in the one model for each behaviour.

4.1. Weather and temporal factors

Table 2 summarises the relationship between time of year, day of the week and weather variables with different aspects of heating behaviour. We find that all weather characteristics (temperature, rainfall, sunshine and wind) have an effect on heating use (both primary and secondary), and all but rainfall had an effect on the duration for which primary heating was used. No weather variables appeared to have an impact on thermostat settings.

Whether or not a day fell within the heating season (October to May) had an effect on all aspects of heating behaviour, even when controlling for all weather variables. This included a small effect on thermostat settings – people were slightly more likely to use settings of 18°C or lower in the summer months. We do not find much of a difference in heating behaviour on weekends compared with weekdays, other than people being slightly less likely to use primary heating on weekends.

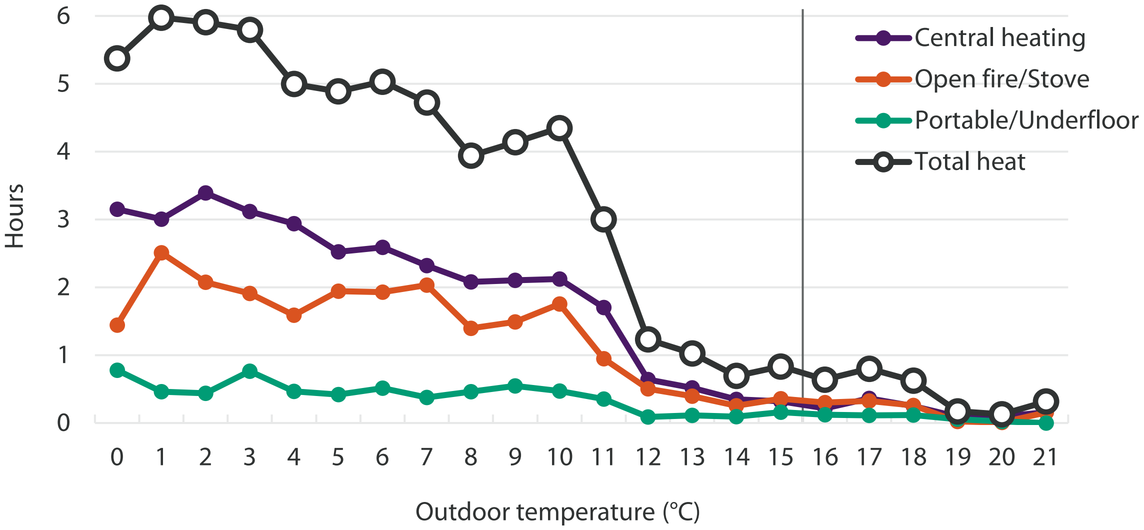
Table 2: Summary table showing the relationship between weather/temporal factors and whether a participant used primary or secondary heating on the reference day, duration of primary heating if used, and thermostat settings used by those who used primary heating and own a thermostat, as revealed by logistic regression models controlling also for dwelling characteristics and sociodemographic characteristics.

	Primary heating use	Secondary heating use	Primary heating duration	Thermostat temperature
Heating season	+	+	+	+
Weekend	–			
Heating degrees	+	+	+	
Rain	+	+		
Sunshine	–	–	–	
Wind	+	+	+	

+ positive relationship; – negative relationship

The relationship between outdoor temperature and heating use is illustrated further in Figure 5. There is clearly a non-linear relationship between the two, with a particularly steep decline in heating use between mean outdoor temperatures of 10°C to 12°C. A low level of heating use endures until outdoor temperatures reach about 19°C. A similar pattern is observed in the percentage of people using heating and the number of days per week heating is used (see Appendix A4).

Figure 5: Mean number of hours for which each type of heating was used in a given day, for each mean daily outdoor temperature recorded, rounded to the nearest °C. Data for the two lowest and two highest temperatures recorded (-2°C, -1°C, 22°C, 23°C) are excluded due to low numbers of observations. Where a participant was not home on the reference day or did not use a given heating type a duration of 0 h is assigned. Vertical line denotes 15.5°C which is the base temperature typically used to calculate heating degree days in Ireland – the outdoor temperature above which it is assumed heating is not needed.



4.2. Dwelling characteristics

The dwelling characteristics of our sample are summarised in Appendix A3. For the most part these characteristics match those from CSO statistics, with the exception of BER. Over half of participants did not know their home's BER, but those that did reported a better distribution of BERs than might be expected, indicating perhaps that people are more likely to know their BER if it is good. Table 3 summarises the relationship between various dwelling characteristics and different aspects of heating behaviour, as well as total energy costs.

People in detached homes were generally more likely to use heating, particularly secondary heating, and to heat for longer than those in other types of homes, but people living in apartments or terraced houses were more likely to use higher thermostat settings.

Their home's BER did not have an impact on whether a participant used heating on a given day, but those living in the most poorly-rated homes did use primary heating for longer times. The same group, however, were more likely to use lower thermostat settings (18°C or below) when they were using their heating. Note, however, that participants who know their BER are likely to be more energy aware than the wider population.

Heat pump and gas boiler owners were less likely to use secondary heating compared with those who owned an oil boiler, whereas those with solid fuel boilers were less likely to use primary heating and more likely to use secondary heating. Homes with heat pumps were heated for longer durations, but were less likely to use high thermostat settings of 21°C or above.

Thermostat owners were more likely to use primary heating but less likely to use secondary heating compared to people who did not have, or did not know if they had, a thermostat. Those who owned smart thermostats in particular were more likely to use their heating for a short time (under 2 h).

Table 3: Summary table showing the relationship between dwelling characteristics and (a) whether a participant used primary or (b) secondary heating on the reference day, (c) duration of primary heating if used, (d) thermostat settings used by those who used primary heating and own a thermostat, and (e) total monthly energy costs as revealed by logistic regression models controlling also for weather/temporal factors and sociodemographic characteristics.

		Primary heating use	Secondary heating use	Primary heating duration	Thermostat temperature	Total energy costs
Ref: Detached	Apartment	−	−	−	+	−
	Semi-D		−	−		−
	Terraced	−	−		+	−
Ref: A/B/C1 BER	C2/C3/D					+
	E/F/G/Exempt			+	−	+
Ref: Oil boiler	Heat pump		−	+	−	
	Gas boiler		−			+
	Solid fuel	−	+	+		−
Ref: No thermostat	Other thermostat	+	−		n/a	
	Smart thermostat	+	−	−	n/a	

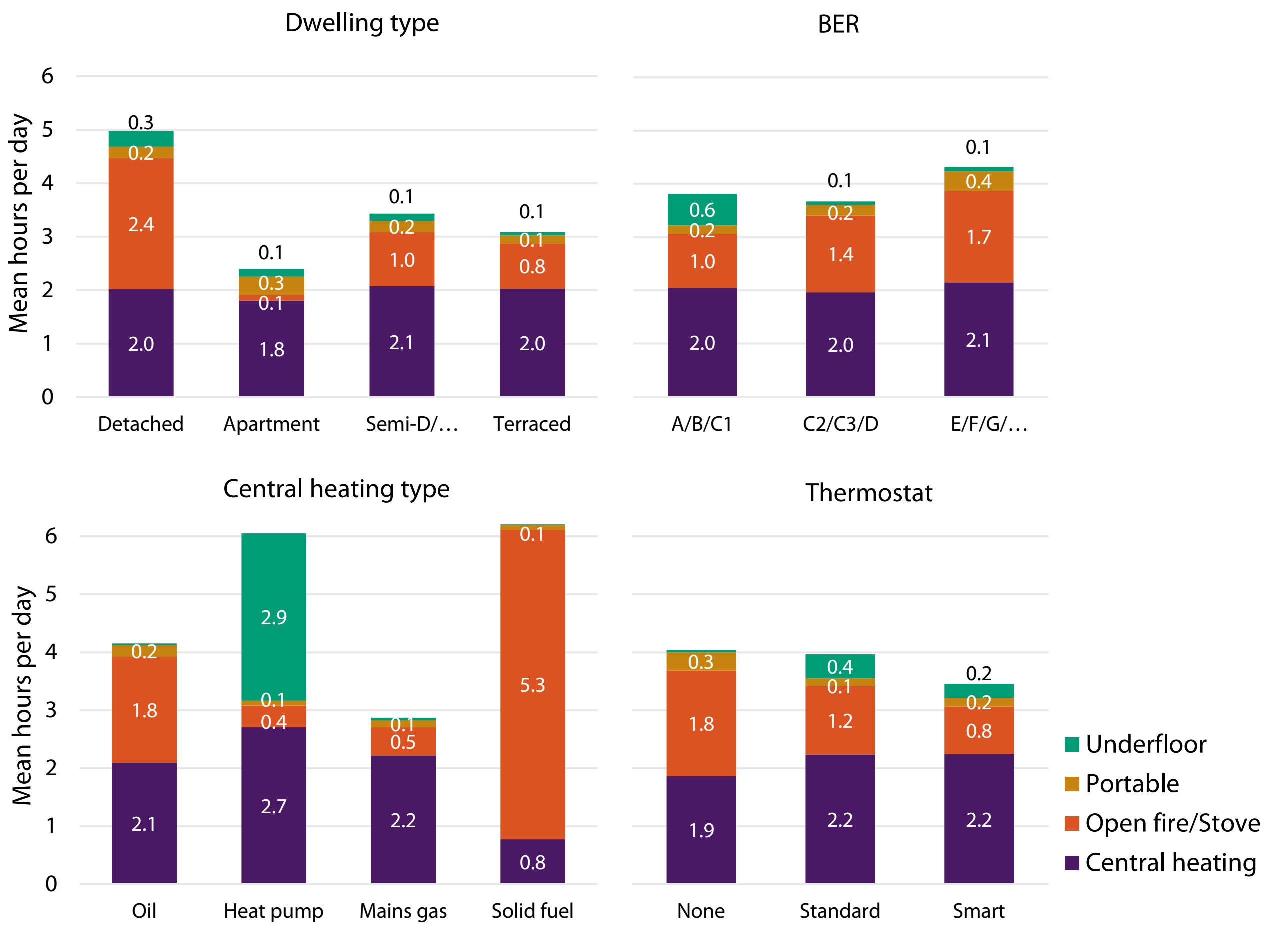
\+ positive relationship; − negative relationship

Figure 6 further illustrates the relationship between different dwelling characteristics and use of different heating types. While there are small variations in central heating use between different dwelling types, the differences in use of open fires and stoves are much more pronounced, with those in detached homes being particularly reliant on this form of heating.

Large variations in behaviour are also seen according to the type of central heating system in the home. Heat pump homes report more use of central and underfloor heating and solid fuel homes report much higher reliance on open fires and stoves, as might be expected, but there are also differences between oil and gas heated homes, with the latter being less reliant on secondary heating sources.

Smaller differences are seen according to a home's BER and presence of an adjustable thermostat.

Figure 6: Mean number of hours for which different types of heating were used in a given day during the heating season, split by (a) dwelling type and (b) BER rating (for those who knew their BER) (c) central heating type (for the four most common options) and (d) thermostat ownership/type.



4.2.1. Differences in energy bills

As well as heating behaviour, we also look at the relationship between dwelling characteristics and household energy expenditure, while controlling for survey wave and sociodemographic factors, for those participants who reported these costs (see Table 8 in Appendix 5 for full model results and Table 3 for summary). As expected, detached homes tended to have higher energy bills than other types of dwelling – these homes reported average monthly energy bills of €274, compared with €197 for apartments, equating to a difference of over €900 a year. There was also a difference between homes with different BERs, although it was not as pronounced – the most energy efficient homes (rated A, B or C1) reported monthly costs of €257 whereas those in the least efficient homes (rated E, F or G) reported just slightly higher costs of €277, which is an extra €240 a year.

Variation in energy bills was also seen according to central heating type, as might be expected, with gas-heated homes having higher costs, solid fuel homes having lower costs, and heat pump homes not differing significantly from oil-heated homes. Interestingly, we did not find any evidence that thermostats saved people money on their energy bills. Smart thermostat owners in fact had higher monthly energy bills than people who did not own a thermostat (€279 vs. €255), although this difference was not statistically significant when controlling for other dwelling and sociodemographic characteristics. Further detail on energy bills reported by different groups can be found in Figure 9 in Appendix A4.

4.3. Sociodemographic & household characteristics

Table 4 summarises the relationship between various sociodemographic and household characteristics, and different aspects of heating behaviour. Disposable household income was one of the characteristics most strongly related to heating behaviour – those on higher incomes, especially those in the highest bracket of €4,000 or more a month, were more likely to use primary heating and use higher thermostat settings, but less likely to use secondary heating. Age and disability status were also associated with higher heat demand. Households with someone aged over 65 were more likely to use primary heating and heat for longer, approximately 20 mins longer a day during the heating season, as did respondents aged over 55. The presence of a person with disability in the household was associated with longer heating times, and households with a child under 18 were more likely to use primary heating in the first place.

Inconsistent effects were seen of renting from a local authority or housing association on heat demand. Compared with owner-occupiers, social housing tenants heated their homes for less time, but were significantly more likely to use high thermostat settings – 29% used settings of 21°C or above compared to 22% of the rest of the sample. We did not find any significant effect of gender on heating behaviour, even when looking only at those participants who live alone. We also found no effect of living in an urban or rural area (while controlling for dwelling factors), other than those living rurally being more likely to use secondary heating. If we do not control for dwelling characteristics, we do see that those living in urban areas are more likely to use primary heating and use higher thermostat settings.

Table 4: Summary table showing the relationship between sociodemographic characteristics and whether a participant used primary or secondary heating on the reference day, duration of primary heating if used and thermostat settings used by those who used primary heating and own a thermostat, as revealed by logistic regression models controlling also for weather/temporal factors variables and dwelling characteristics.

	Primary heating use	Secondary heating use	Primary heating duration	Thermostat temperature
Male				
Older age			+	
Higher income	+	–		+
Social grade				
Degree	+			–
Employment				
Urban area		–		
Social housing			–	+
Household size			+	
Under 18s in home	+			
Over 65s in home	+		+	
Disability in home	+		+	

+ positive relationship; – negative relationship

4.4. Psychological factors

The relationships between selected psychological factors and heating behaviour are summarised in Table 5. Higher worry about cost of living was associated with a slightly lower likelihood of using primary heating, but had no impact on any of the behaviours modelled. Higher worry about climate change, on the other hand, had no impact on using heating in the first place, but was associated with a higher likelihood of heating for shorter times (under 2 h) and a lower likelihood of using high thermostat settings (21°C or above). Those who self-reported a higher understanding of how to save energy were less likely to use primary heating and to use high thermostat settings, but did not heat for shorter times. The effort participant perceived others as making to save energy at home had no significant relationship with their own heating behaviour.

Table 5: Summary table showing the relationship between psychological factors and whether a participant used primary or secondary heating on the reference day, duration of primary heating if used and thermostat settings used by those who used primary heating and own a thermostat, as revealed by logistic regression models controlling also for weather/temporal factors, dwelling characteristics and sociodemographic characteristics.

	Primary heating use	Secondary heating use	Primary heating duration	Thermostat temperature
Cost-of-living worry	–			
Climate worry			–	–
Understanding	–			–
Effort of others				

+ positive relationship; – negative relationship

5. Discussion

5.1. Overestimation of heat demand in energy performance models

Arguably the most important finding from our research, in keeping with existing evidence, is that simplified energy performance models such as the DEAP significantly overestimate how much Irish households heat their homes, particularly with regards to heating duration. During the heating season of October to May, we find that people heat their homes for an average of 3.9 h a day, about half the duration assumed in DEAP.

There is a certain level of uncertainty around our estimate, as respondents report heating duration in 1 h intervals for each heating type. The fact that estimates are derived from one individual's reporting of use for the full household could mean that these are underestimated slightly. On the other hand, the fact that we take total heating duration to be a sum of the durations for different heating types (central heating, open fires/stoves, portable heaters and underfloor heating) means that our estimate is likely to be an upper bound, as it does not account for different heating types being used concurrently.

Our study does have a clear advantage over others in gathering data from a large, nationally representative sample, incorporating secondary heating. A previous Irish study that estimated a slightly longer daily heating duration of approximately 5 h derived its estimate from a comparatively small sample of mostly detached homes within a certain geographical area.[8] In fact, this figure is almost exactly in agreement with our estimates of total heating duration specifically for detached homes. An ideal approach would be to validate the self-reported methodology in BETT with actual radiator temperatures from a subsample of homes.

Our analysis also suggests that people use lower thermostat settings in living areas than assumed in the model (typically 20°C rather than 21°C) and do not necessarily use heating in the morning as well as the evening. Further research into thermostat settings in other rooms and more granular data on heating schedules are required to validate these findings.

It is important to note that the purpose of the DEAP is not necessarily to provide an accurate prediction of energy consumption of every home but rather to facilitate comparison between different dwellings. Indeed, the high degree of variability we find in behaviour shows it would be impossible to predict the consumption of any given household using a generalised model. That said, a systematic underestimation of the average heating demand of Irish households will have an impact on comparisons, and may partially account for the lack of differentiation in actual energy consumption between dwellings with different BERs.[15] Basing assumptions of behaviour on normative of views of what a "typical" Irish household should look like, such as the nuclear family, also runs the risk of disadvantaging households that do not fit this mould in some way.[26]

5.2. Nuances in seasonal factors affecting heating

Another way in which our findings differ from energy performance models is with regards to there being a clearly defined "heating season" during which people use heating and outside of which they don't. While we do find higher use of space heating from October to May compared with the summer months, even when controlling for weather, heating behaviour is not uniform within this period. Less than half our sample used any form of heating in a given day in our October and May waves. This is supported by evidence from the UK that suggests that heating patterns vary at different points in the heating season and that there is considerable variability in the point in the year at which households first turn on the heating.[27,28]

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[26] Hausner, B. et al. (2023). Energy consulting: A tool for inclusion? https://userstcp.org/wp-content/uploads/2023/09/Case-Study_Energy-consulting_Austria-DOI.pdf

[27] Pullinger, M. et al (2022). Domestic heating behaviour and room temperatures: Empirical evidence from Scottish homes. *Energy and Buildings 254*, 111509. https://doi.org/10.1016/j.enbuild.2021.11150.

[28] Kane,T, Firth, SK & Lomas, KJ (2015). How are UK homes heated? A city-wide, socio-technical survey and implications for energy modelling. *Energy and Buildings 86*, 817-832. https://doi.org/10.1016/j.enbuild.2014.10.011.

As mentioned previously, we also find that a low level of space heating persists during the summer and on warmer days. A mean daily outdoor temperature of 15.5°C is typically considered the threshold below which space heating is required, but our data show there is a much steeper decline in heating use at the lower temperature of approximately 12°C, with a low level of heating persisting up to about 19°C. Our findings also provide further evidence that many aspects of weather affect heating behaviour besides temperature.

5.3. Heterogeneity in heating behaviour across dwelling types

We find significant differences in heating behaviour across different dwelling types and heating systems, which largely account for differences between urban and rural areas. People living in detached homes were more likely to use heating and heated for longer periods (especially secondary heating), as found by others previously, but used lower thermostat settings than people living in apartments or terraced houses, perhaps as a compensatory energy saving measure. The differences found in behaviour are reflected in reported energy bills. As expected, people living in detached homes reported the highest energy bills, and apartment dwellers the lowest.

We also find a high degree of variability in behaviour according to the primary heating system installed in a home, particularly with regards to secondary heating. People using oil to heat their homes relied much more on secondary heating than those using a gas boiler or heat pump. These differences in behaviour may have important implications when it comes to switching homeowners from fossil fuel to renewable heating. On the one hand, switching oil-heated homes to heat pumps could result in even greater emissions savings than previously assumed, if the switch also causes these homes to reduce their use of secondary heating. On the other hand, it may be more difficult to get these homes to switch due to a larger required change in heating habits. Interestingly, there was no significant difference in total energy bills found between heat pump homes and oil-heated homes.

As expected, people in heat pump homes heat for longer durations than those with traditional boilers. Different heating patterns required by new low carbon technologies will also need to be considered in DEAP as these become more common.

Compared with dwelling type and heating system, the effect of a dwelling's BER had a relatively smaller impact on occupant behaviour, although statistically significant differences were seen between the most and least efficient homes. Participants living in homes rated E or below heated for slightly longer times than those in homes rated C1 and above, but were more likely to use thermostat settings of 18°C or below. It should be noted that most participants did not know the BER rating of their home, and those who were aware might not be representative of the full population.

5.3.1. No evidence of lower energy bills among thermostat owners

Perhaps unexpectedly, we find no evidence that having an adjustable thermostat (smart or otherwise) results in lower energy bills – if anything bills appear to be a little higher. This may be partly due to the fact that thermostat owners are more likely to rely on primary heating rather than secondary heating. It is also possible that people with thermostats heat their homes to a higher temperature, as found in the UK.[9]

5.4. Individual differences in heating behaviour

Our findings regarding sociodemographic differences in heating behaviour are largely in keeping with previous research. Older age and disability are associated with higher heat demand, through increased and prolonged use of primary heating rather than higher thermostat settings. Higher income on the other hand was associated with both higher use of primary heating and higher thermostat settings. It is possible that the former older age group have an increased need for heat, perhaps due to spending more time in the home, whereas the latter high-income group use more heat simply because they are less sensitive to cost. These nuances are important to bear in mind when constructing measures of energy poverty, as explored in a separate report.[29]

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[29] SEAI (2024). Energy poverty in Ireland: Analysis of 2023 data from the Behavioural Energy and Travel Tracker.

Whereas a previous study found lower heat demand in rented homes compared with owner-occupied (as measured by gas consumption), we see differences only for social housing tenants, when controlling for other factors. Curiously, this group heated their homes for less time but were also much more likely to use high thermostat settings of 21°C or above. The reason for this is an area that warrants further investigation – it is possible that a simple educational intervention could be helpful for this typically lower-income group.

5.4.1. Psychological factors related to heating behaviour

The psychological factors we investigated were related to behaviour in different ways. Participants who were highly worried about cost of living were less likely to use central heating in a given day than those who reported lower worry, but once they did they were no less likely to heat for extended times or to use higher thermostat settings. This pattern was reversed among those who were highly worried about climate change – they were no less likely to use heating than those who reported lower worry, but heated for less time and at lower temperatures. Self-reported understanding of how to save energy was associated with a lower likelihood of using primary heating and of using higher thermostat settings, suggesting there is potential for education to change behaviour.

The different mechanisms by which the two types of worry led to energy saving are reminiscent of the different types of thinking described by Dual Process Theory.[30] Simply avoiding turning on the heating is suggestive of a simple "System 1" type heuristic for saving energy, whereas managing heating duration is closer to "System 2" deliberative thinking. This may reflect a lack of time and capacity among those worried about costs to manage their energy use in the most effective way and highlights the need to provide this cohort with simple easy-to-follow advice that doesn't lead them to simply deprive themselves of heat altogether. Arguably, using a lower thermostat setting is a simpler behaviour to adopt than managing heating duration, but this is only relevant to the half of the population that own thermostats in the first place.

Unlike some previous studies we do not find evidence of a social norm-type effect on heating behaviour. Thinking that others were making more of an effort to save energy had no impact on a participant's own heating behaviour. However, our measure of perceived effort is not specific to heating and further research is warranted in this area.

5.5. Conclusion

This report details a comprehensive analysis of heating behaviour in Ireland using a large nationally representative sample. It adds to existing evidence that suggests simplified energy performance models such as the Dwelling Energy Assessment Procedure (DEAP) significantly overestimate the average duration for which people heat their homes and thermostat settings for living spaces, although there is a high degree of variability in both. It also highlights several factors that affect heating behaviour, which may in some cases warrant separate model assumptions, or at least caution in interpreting model predictions, and should guide policy interventions to reduce heating demand through behaviour change.

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[30] Kahneman, D. (2011). *Thinking, Fast and Slow.* Doubleday Canada.

Appendices

A1. Heating behaviour questions

Q. Was your home heated using any of the following on [reference day]?
Select **all** that you know were used over the course of the day, even if you weren't home at the time.
If you're not sure what category your heating falls into, please select the option that fits best.
[*Wave 3 +*] If you have a heat pump, count this under central heating (not underfloor).

1. Central heating (including storage heaters)
2. Portable heater
3. Open fire/stove/range or similar
4. Electric underfloor heating (not central heating)
5. Home wasn't heated at all

[*if used central heating*]

Q. At what times of day was the central heating switched on, on [reference day]?
Select **all** times when the heating was set to come on, to the best of your knowledge.

1. Before 8am
2. 8am – 4pm
3. 4pm – 7pm
4. 7pm – 11pm
5. After 11pm
6. Don't know

Q. How long was the central heating on for in total?
If you're not sure, please just give it your best guess.

- 1. Less than 1 hour/ 2. 1 – 2 hours/…/13. 12 hours+

Q. Were any unoccupied rooms heated?

1. Yes
2. Yes – at a lower temperature
3. No
4. Don't know

[*if used portable heater*]

Q. How many portable heaters were used at a time on [reference day]?

- 1 – 5+

Q. What type of portable heaters were used?
Select **all** that apply.

1. Electric
2. Gas/Oil/Other

Q. At what times of day were portable heaters used?
Select **all** that apply.

1. Before 8am
2. 8am – 4pm
3. 4pm – 7pm
4. 7pm – 11pm
5. After 11pm

Q. How long were portable heaters switched on for in total on [reference day]?
If you're not sure, please just give it your best guess.

- 1. Less than 1 hour/ 2. 1 – 2 hours/…/13. 12 hours+

[*if used open fire/stove*]

Q. How many open fires/stoves (or similar) were lit at a time on [reference day]?

- 1 – 5+

Q. What type of fuel was primarily used in any open fires/stoves?

1. Wood
2. Coal
3. Smokeless coal
4. Briquettes
5. Turf
6. Other

Q. How long were open fires/stoves lit for in total?

If you're not sure, please just give it your best guess.

- 1. Less than 1 hour/ 2. 1 – 2 hours/ … /13. 12 hours+

[*if used electric underfloor*]

Q. How many rooms were heated using electric underfloor heating at a time on [reference day]?

- 1 – 5+

Q. At what times of day was electric underfloor heating switched on?

Select **all** that apply.

1. Before 8am
2. 8am – 4pm
3. 4pm – 7pm
4. 7pm – 11pm
5. After 11pm

Q. How long was electric underfloor heating switched on for in total?

If you're not sure, please just give it your best guess.

- 1. Less than 1 hour/ 2. 1 – 2 hours/ … /13. 12 hours+

[*if own thermostat*]

Q. What room temperature is your thermostat currently set to (for living spaces when the heating is on)?

- 1. 15 °C or less, 2. 16°C, … ,10. 24 °C or more, 11. Don't know

A2. Calculation of heating degree-days

The following approach is used to calculate heating degree-days in our analysis, using a base temperature of 15.5°C.[31]

- **Case I.** The minimum air temperature (T_{min}) above the base temperature (T_{base}). In this case there are no degree-days below the base temperature and the degree-days above are given by $1/2(T_{max} + T_{min}) - T_{base}$.
- **Case II.** The maximum air temperature (T_{max}) below the base temperature. In this case there are no degree-days above the base temperature and the degree-days below are given by $T_{base} - 1/2(T_{max} + T_{min})$.
- **Case III.** The maximum air temperature above and the daily minimum air temperature below the base temperature but the mean temperature which equals $1/2(T_{max} + T_{min})$, greater than the base temperature. In this case degree-days above are given by $1/2(T_{max} - T_{base}) - 1/4(T_{base} - T_{min})$ and degree-days below by $1/4(T_{base} - T_{min})$.
- **Case IV.** The maximum air temperature above and the minimum air temperature below the base temperature but the mean temperature which equals $1/2(T_{max} + T_{min})$, less than the base temperature. In this case degree-days above are given by $1/4(T_{max} - T_{base})$ and degree-days below are given by $1/2(T_{base} - T_{min}) - 1/4(T_{max} - T_{base})$. If the mean temperature is equal to the base temperature the same results obtain using either the formula for Case III or Case IV.

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[31] Methodology obtained from Met Eireann.

A3. Dwelling characteristics

Table 6: Dwelling characteristics of the sample.

		Proportion
House type	Detached house	40%
	Apartment/flat/bedsit	10%
	Semi-detached/end of terrace house	36%
	Terraced house	14%
BER	A/B/C1	21%
	C2/C3/D	18%
	E/F/G/Exempt	5%
	Don't know	56%
Central heating type	Oil boiler	40%
	Heat pump	5%
	Gas boiler	31%
	Solid fuel	7%
	Other/Don't know	14%
	None	4%
Thermostat	Smart thermostat	13%
	Other thermostat	32%
	No thermostat	50%
	Don't know	6%

A4. Additional graphs

Figure 7: Proportion of participants using different types of heating in a given day and mean number of days on which heating was used in the preceding week, across survey waves in 2023. Portable heaters and underfloor heating are pooled due to low prevalence. Shading used to indicate waves conducted during the heating season.

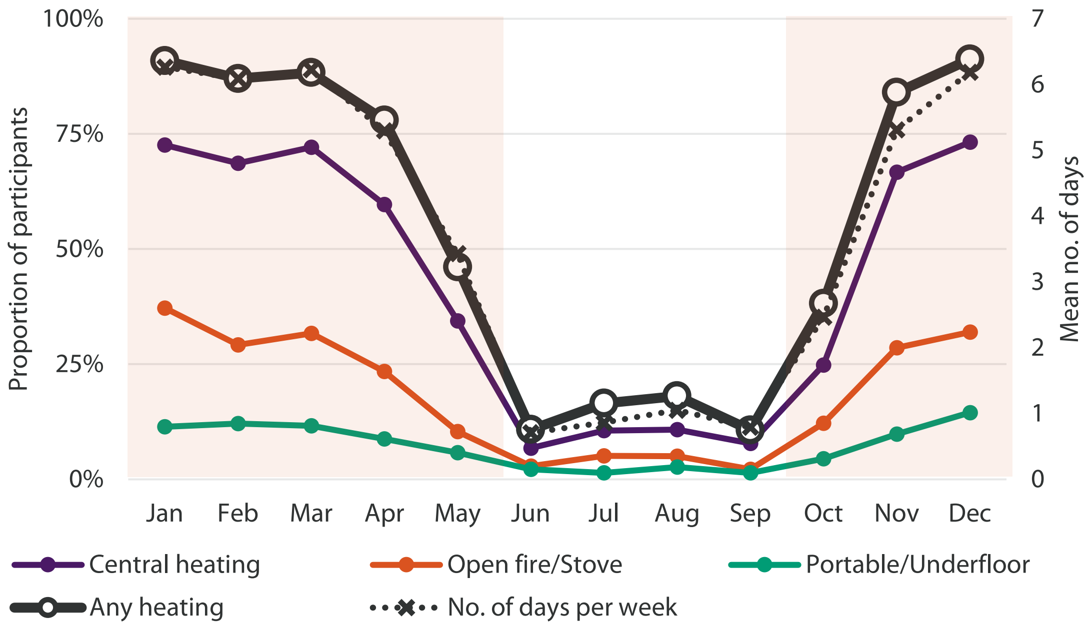


Figure 8: Proportion of participants using different types of heating in a given day and mean number of days on which heating was used in the preceding week, for each mean daily outdoor temperature recorded, rounded to the nearest °C. Data for the two lowest and two highest temperatures recorded (-2°C, -1°C , 22°C, 23°C) are excluded due to low numbers of observations. Vertical line denotes 15.5°C which is the base temperature typically used to calculate heating degree days in Ireland – the outdoor temperature above which it is assumed heating is not needed.

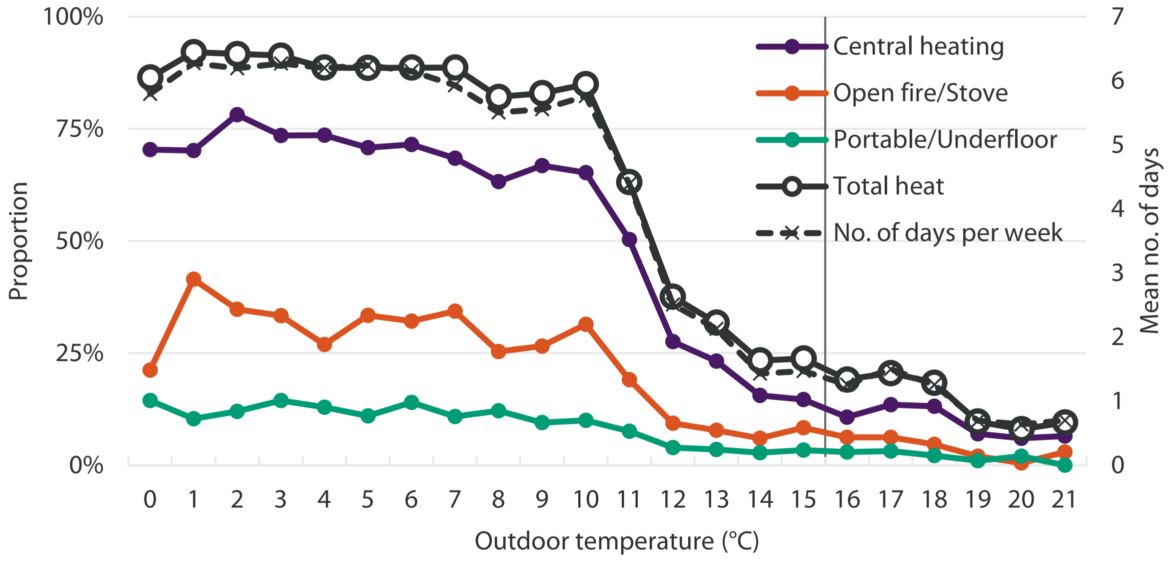
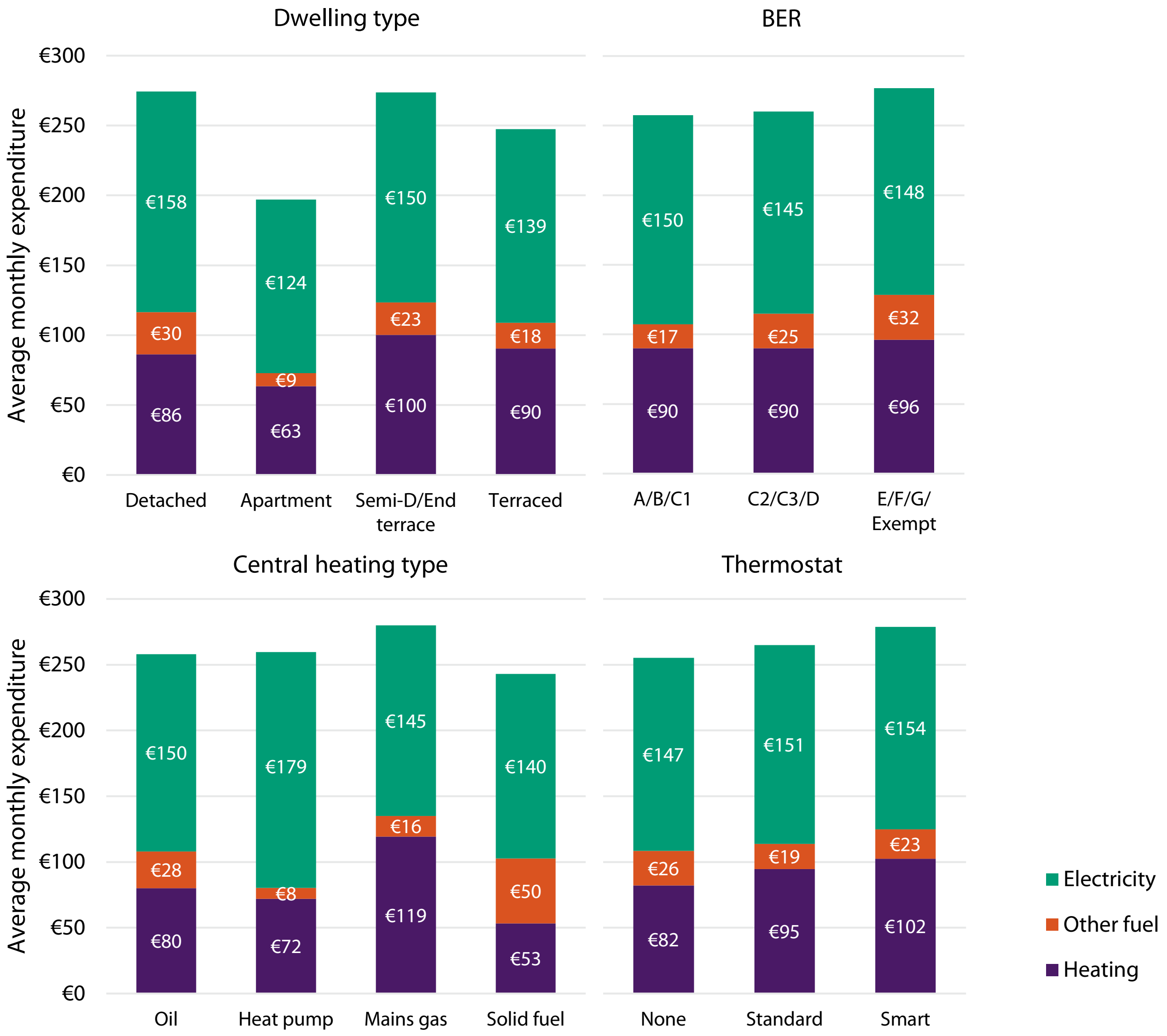


Figure 9: Average monthly expenditure on energy bills for those participants that reported these costs (n=9,601), split by (a) dwelling type and (b) BER (for those who knew their BER) (c) central heating type (for the four most common options) and (d) thermostat ownership/type.



A5. Regression model results

Table 7: Results of logistic regression models examining the relationship between weather/time, dwelling characteristics, sociodemographic characteristics and psychological factors with different aspects of heating behaviour: (a) whether a participant used primary or secondary heating on the reference day, (b) duration of primary heating if used (over 2h vs. under; over 4 h vs. under) and (c) thermostat settings used by those who used primary heating and own a thermostat (19°C and above vs. 18°C and under; 21°C and above vs. 20°C and under). Results pertaining to "don't know" categories or to too few respondents omitted from table for brevity.

		Heating use		Primary heating duration		Thermostat settings	
		Primary	Secondary	> 2 h	> 4 h	19°C +	21°C +
Weather/time							
Ref: Jun-Sep	Heating season (Oct-May)	1.68 (0.07)***	1.51 (0.1)***	0.69 (0.14)***	0.27 (0.19)	0.48 (0.2)*	0.07 (0.22)
Ref: Weekday	Weekend	-0.12 (0.05)*	0.1 (0.06).	-0.04 (0.07)	-0.1 (0.07)	-0.05 (0.1)	-0.16 (0.1)
	Heating degrees	0.21 (0.01)***	0.15 (0.01)***	0.15 (0.01)***	0.14 (0.01)***	0 (0.01)	0.01 (0.02)
Ref: 0 mm	Very wet (> 10 mm)	0.51 (0.12)***	0.23 (0.14).	0.08 (0.16)	0.13 (0.19)	0.35 (0.25)	-0.43 (0.29)
	Wet (1 - 10 mm)	0.29 (0.05)***	0.2 (0.06)***	0.11 (0.07)	0.01 (0.08)	0.16 (0.11)	0.09 (0.11)
Ref: < 1 h	Med sun (1-5 h)	-0.13 (0.06)*	0.04 (0.06)	-0.11 (0.07)	-0.14 (0.08).	0.05 (0.11)	0 (0.11)
	Sunny (5h+)	-0.27 (0.07)***	-0.16 (0.07)*	-0.21 (0.09)*	-0.11 (0.1)	-0.07 (0.13)	0.02 (0.14)
Ref: < 20 km/h	Windy (20 km/h+)	0.27 (0.05)***	0.43 (0.06)***	0.17 (0.07)*	0.15 (0.08).	-0.03 (0.11)	-0.06 (0.11)
Dwelling characteristics							
Ref: Detached	Apartment	-0.29 (0.1)**	-1.18 (0.13)***	-0.32 (0.14)*	-0.15 (0.15)	0.47 (0.23)*	0.28 (0.22)
	Semi-D	0.03 (0.06)	-0.47 (0.07)***	-0.16 (0.08)*	-0.06 (0.09)	0.09 (0.12)	0.18 (0.13)
	Terraced	-0.17 (0.08)*	-0.71 (0.1)***	-0.13 (0.11)	-0.04 (0.12)	0.32 (0.17).	0.34 (0.17)*
Ref: A/B/C1 BER	C2/C3/D	0.14 (0.08).	0.1 (0.09)	-0.02 (0.1)	-0.12 (0.12)	-0.23 (0.14).	-0.13 (0.14)
	E/F/G/Exempt	0.09 (0.12)	0.23 (0.13).	0.51 (0.16)**	0.42 (0.16)**	-0.95 (0.23)***	-0.26 (0.26)
Ref: Oil boiler	Heat pump	0.15 (0.12)	-1.48 (0.19)***	1.39 (0.17)***	1.92 (0.15)***	0.06 (0.18)	-0.58 (0.2)**

	Gas boiler	0.07 (0.07)	-0.86 (0.08)***	0.05 (0.08)	0.17 (0.09).	0.21 (0.13).	0.11 (0.13)
	Solid fuel	-2.2 (0.12)***	1.66 (0.1)***	0.01 (0.2)	0.74 (0.21)***	0.32 (0.4)	0.01 (0.19)
Ref: No thermostat	Other thermostat	0.17 (0.06)**	-0.33 (0.06)***	-0.12 (0.07)	0.03 (0.08)		
	Smart thermostat	0.24 (0.08)**	-0.5 (0.09)***	-0.33 (0.09)***	-0.06 (0.11)		
Sociodemographic characteristics							
Ref: Female	Male	-0.02 (0.05)	0 (0.06)	0.04 (0.07)	0.02 (0.07)	-0.08 (0.1)	0.05 (0.1)
Ref: 18-34	35 - 54	0.07 (0.07)	0.02 (0.08)	0 (0.09)	0.09 (0.1)	0.13 (0.14)	-0.13 (0.14)
	55+	0.01 (0.09)	0.17 (0.09).	0.38 (0.12)**	0.47 (0.13)***	0.23 (0.18)	-0.18 (0.18)
Ref: <€2k	€2k - €4k	0.11 (0.06).	-0.18 (0.07)**	0.06 (0.08)	0.09 (0.09)	0.27 (0.13)*	0.28 (0.14)*
	€4k+	0.37 (0.08)***	-0.22 (0.08)**	0 (0.1)	0.09 (0.11)	0.4 (0.15)**	0.36 (0.16)*
Ref: ABC1	C2DEF	-0.07 (0.05)	0.07 (0.06)	-0.09 (0.07)	-0.02 (0.08)	0.07 (0.11)	-0.11 (0.11)
Ref: Below degree	Degree	0.12 (0.05)*	0.02 (0.06)	-0.06 (0.07)	-0.06 (0.08)	-0.26 (0.1)*	0.05 (0.11)
Ref: Employed	Not employed	0.09 (0.06)	0.11 (0.06).	-0.02 (0.08)	0.09 (0.08)	0.15 (0.12)	-0.07 (0.12)
Ref: Rural	Urban	-0.02 (0.06)	-0.27 (0.07)***	0.1 (0.08)	-0.07 (0.09)	0.1 (0.12)	0.09 (0.12)
Ref: Own home	LA or HA	-0.04 (0.09)	-0.21 (0.11).	-0.55 (0.12)***	-0.37 (0.14)**	0.1 (0.18)	0.73 (0.17)***
	Rent	0.01 (0.07)	-0.1 (0.08)	0 (0.1)	-0.07 (0.11)	-0.08 (0.16)	0.09 (0.17)
	Hh size	0.01 (0.02)	0.03 (0.02)	0.1 (0.03)**	0.03 (0.03)	0.07 (0.05)	0.02 (0.05)
	U18s in hh	0.16 (0.07)*	0.05 (0.07)	-0.08 (0.09)	-0.16 (0.1)	0.09 (0.13)	0.09 (0.14)
	Over 65s in hh	0.17 (0.07)*	0.1 (0.07)	0.19 (0.09)*	0.33 (0.09)***	0.18 (0.14)	0.28 (0.15).
	Disability in hh	0.12 (0.06)*	0.04 (0.06)	0.17 (0.07)*	0.18 (0.08)*	-0.04 (0.11)	0.02 (0.12)
Psychological factors							
Ref: Low worry	Hi cost-of-living worry	-0.11 (0.05)*	-0.09 (0.06)	-0.11 (0.07).	-0.07 (0.07)	-0.12 (0.1)	0.08 (0.11)
	Hi climate worry	-0.03 (0.05)	0.06 (0.06)	-0.21 (0.07)**	-0.08 (0.07)	-0.09 (0.1)	-0.28 (0.1)**
Ref: Low understanding	Hi understanding	-0.12 (0.06)*	0.05 (0.06)	-0.04 (0.07)	0.05 (0.08)	-0.05 (0.12)	-0.37 (0.12)**

	Hi effort of others to save	0.11 (0.06).	-0.03 (0.06)	0.11 (0.07)	-0.03 (0.08)	-0.01 (0.11)	0.13 (0.11)

Table 8: Results of linear regression model examining the relationship between dwelling characteristics and sociodemographic characteristics, and total monthly household energy costs (heating, electricity and other fuels), for those respondents who reported non-zero costs, while controlling for survey wave/month. The cube root of the dependent variable (cost) was used to correct for heteroskedasticity. Results pertaining to wave/month, "don't know" categories or too few respondents omitted from table for brevity.

		Total energy costs
Dwelling characteristics		
Ref: Detached	Apartment	-0.68 (0.05)***
	Semi-D	-0.2 (0.03)***
	Terraced	-0.35 (0.04)***
Ref: A/B/C1	C2/C3/D	0.1 (0.04)**
	E/F/G/Exempt	0.2 (0.06)***
Ref: Oil boiler	Heat pump	0.12 (0.07).
	Gas boiler	0.29 (0.03)***
	Solid fuel	-0.2 (0.05)***
Ref: No thermostat	Other thermostat	-0.02 (0.03)
	Smart thermostat	0.05 (0.04)
Sociodemographic characteristics		
	Male	-0.05 (0.02)
Ref: 18-34	35 - 54	-0.01 (0.03)
	55+	-0.1 (0.04)*
Ref: <€2k	€2k - €4k	0.09 (0.03)**
	€4k+	0.16 (0.04)***
	C2DEF	0.05 (0.03).
	Degree	-0.12 (0.03)***
	Not employed	-0.12 (0.03)***
	Urban	0.01 (0.03)
Ref: Own home	LA or HA	0.05 (0.04)
	Rent	0.03 (0.04)
	Hh size	0.24 (0.01)***
	U18s in hh	-0.03 (0.03)
	Over 65s in hh	0.05 (0.03)
	Disability in hh	0.1 (0.03)***

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